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33.2: A Full-Color Thresholdless Antiferroelectric LCD Exhibiting Wide Viewing Angle with Fast Response Time

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Abstract: We have conducted researches on Antiferoelectric Liquid Crystal (AFLC) by particularly focusing on the pretransitional effect in the electric-field-induced AF-F phase transition of AFLC, and on the application of this phenomenon to the display device. We developed a TFT-LCD using a thresholdless AFLC (TLAFLC) based on the pretransitional effect of the AFLC. The TLAFLC device shows V-shaped electro-optic characteristics without hysteresis. Taking advantage of this characteristic, we established an idea to drive this device with TFTs; this allows us to realize an image sticking free LCD. We accomplished a 5.5 inch diagonal 240×320×3 dots prototype display device which can display full-color moving pictures. High quality display whose quality was as high as a CRT display was achieved by this prototype LCD. This paper will explain LC materials, the device structure, the specifications of the prototype display, and its performance.

INTRODUCTION

A Surface Stabilized Ferroelectric Liquid Crystal (SSFLC) device which has been manufactured and distributed recently [1], does not have an enough capacity for the demanded full-color display. By way of comparison, an AFLC device whose gray scales are controlled by a multidomain method has problems such as high power consumption and degradation of contrast [2,3]. Dr. Schadt et al., introduced a display using a Deformed Helix Ferroelectric Liquid Crystal, which has the deformed helical structure. However, this display should still cope with subjects such as shortage of contrast and display sticking which remain unsolved [4,5].

An In-Plane Switching mode (IPS mode) display device, which drives the nematic liquid crystal at in-plane electric field, was developed recently. Notice of its wide viewing angle as well as the FLC/AFLC has been taken [6]. However, it brings a problem of low light efficiency because of low aperture ratio. Therefore, it is pointed out that the IPS mode display device is not suitable for portable use because a backlight requires high power consumption.

We focused on the AFLC, more particularly, its pretransitional effect in the electric-field-induced AF-F phase transition, and have been investigating it since early 1992. As a result, we have developed a TLAFLC device, which shows V-shaped electro-optic characteristics without threshold [7,8,9,10]. This technique brings up the wide viewing angle, good gray scale characteristics without inversion, and high speed response which cannot be obtained by other LCD techniques. This paper will introduce these phenomena and techniques. We confirmed TV image displaying with wide viewing angle by the prototype 5.5 inch diagonal full-color display, the performance of which will be reported.

EXPERIMENTAL RESULTS

Geometry of the TLAFLC Display

Fig. 1 shows the structure of the TLAFLC cell. LC molecules are aligned horizontal to two glass substrates whose opposing sides have transparent electrode films. The TLAFLC is classified in smectic phase having a layer structure. Each of the layers is formed perpendicularly to the glass substrates. The cell is set between crossed polarizers, keeping one polarizer parallel to the smectic layer normal.

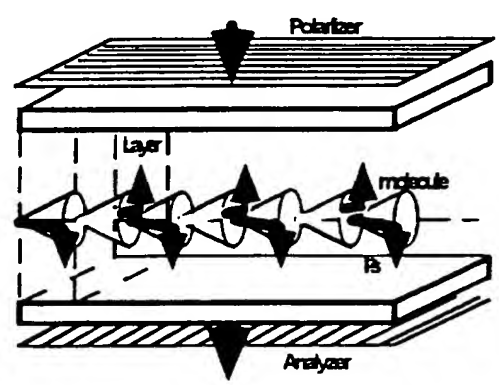
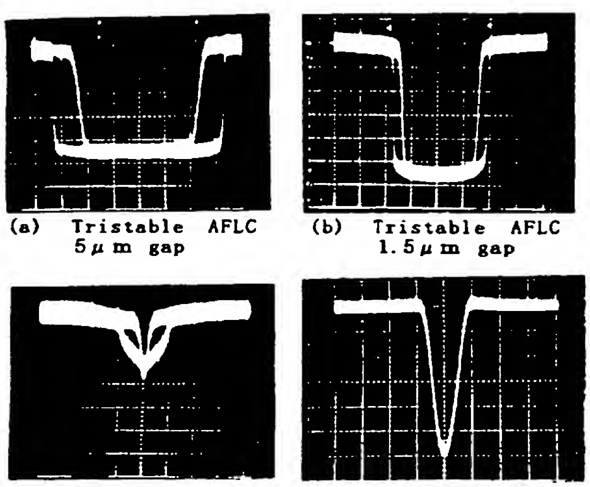


Fig. 1 Geometry of TLAFLC device

Each of molecules in the TLAFLC tilts at a regular angle to the smectic layers, and has dipole moments which are perpendicular to the long axes of the molecules. When the dipole moments are oriented in the same direction by an electric field, they become spontaneous polarizations. To discuss the molecular arrangements of the TLAFLC, which was used in this investigation and the expression condition, we made an experiment. First, we measured selective reflection wave lengths, and observed

conoscopic figures to determine the LC phase of the TLAFLC in bulk state. Only a half-pitch selective reflection band of the TLAFLC was observed, but a full-pitch selective reflection band of it was not observed. We observed a conoscopic figure showing melatopes which were divided in two having a regular between them in the direction that was perpendicular to the electric field applying direction. We determined from these characteristics that the TLAFLC had SmCA* phase. Then, we made homogeneously aligned cells of the TLAFLC and tristable AFLC, the thicknesses of whose LC layers were different from each other, and we measured their electro-optic characteristics. We also measured a relationship among each of the amounts of the transmission lights and applied voltage, when a triangular electric field of ± 20V and 0.1 Hz was applied to the cells. Fig. 2 shows the results.

Electro-optic characteristic curves of the tristable AFLC cells were almost the same even if the thicknesses of the LC layers were different. As the cell gaps of the TLAFLC cells become narrower, however, electro-optic characteristic curves of the TLAFLC cells changed to V-shaped curves. Therefore, the area of the tristable AFLC is apart from interfaces of the TLAFLC cell, whose gaps are large, and areas of the TLAFLC are near the interfaces.



(a) Tristable AFLC 5μm gap (b) Tristable AFLC 1.5μm gap

(c) TLAFLC 5μm gap (d) TLAFLC 1.5μm gap

Fig. 2 Electro-optic characteristics

To consider a molecular arrangement model of the TLAFLC, we defined the state of liquid crystal molecules, which are in adjacent two layers and tilt in the same direction, as the ferroelectric ordering F, and the state of the molecules which tilt in the opposite direction to each other as the antiferroelectric ordering A. The TLAFLC is characterized in that it has an extremely large phase transition pretransitional-effect. And energy barriers in the ferroelectric state and the antiferroelectric state may be lower than those of the tristable AFLC. Therefore, it is considered that the molecular arrangement model may take an intermediate state between the orderings A and F in which the molecules are not disposed in the same plane. Therefore, it is pointed out that the structure of the TLAFLC differs from that of the conventional tristable AFLC. Under the field free situation, the dipole moments are canceled out within two adjacent layers, and the average direction of the molecules is the same as the direction of the normal line of the layer, so that optical dark state may be occured. When an electric field is applied, each of the molecules is rotated like drawing the corn with effects caused by spontaneous polarizations and the electric field. The average optical axis is changed continuously in accordance with the electric field strength. This behavior is shown in Fig. 3. It can be considered from these models that although the AFLC having an extremely large pretransitional effect behaves like the tristable AFLC in the bulk state, the AFLC may be transferred to the TLAFLC when it is disposed in the homogeneously aligned cell which has small gaps. Based on these experimental results, we interpret that the TLAFLC effect is induced by an interface.

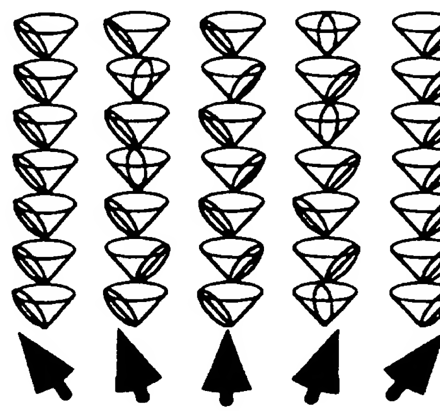


Fig. 3 Changes in molecule orientation in TLAFLC caused by applying electric field

TLAFLC material

The helical pitch of the TLAFLC is over 1.5 μm, so that it is considered that the helix is unwound in the cell. The average directions of the molecules are changed continuously by applying the electric field, so that the optical axes directions rotate continuously. This change in the molecule orientation seems to be analog gray scale.

It is obvious from Fig. 4 that the change in the molecule orientation is not multidomain which is featured in the SSFLC, or the tristable AFLC for simple matrix driving.

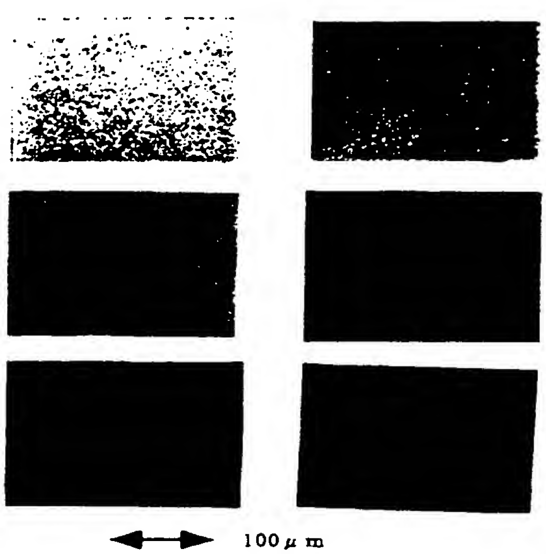


Fig. 4 Microscopic appearance of gray scale in TLAFLC

This figure is reproduced in color on page 1134.

The TLAFLC device unlike the SSFLC does not have bistability, so that it must be driven with active matrix method. However, full-color displaying with wide viewing angle can be accomplished. It shows high speed response because the spontaneous polarization is large. Table 1 shows the physical properties of the TLAFLC which is used for the developed prototype.

Table 1 Physical properties of the TLAFLC

X −30℃ SmC_A^* 69℃ SmA 80℃ Iso	
Spont. polarization	229nC/cm²
Cone angle	32°
Helical pitch	1.5 μm

The panel preparation and manufacture

The liquid crystal in the device is aligned by applying a polyimide alignment film for low pretilt. It is known that switching voltage for the AFLC greatly depends on the thickness of the alignment film. Further, it has been clarified that the contrast depends on the flatness of the surface of the alignment film. Our experiment showed that switching voltage of a cell whose alignment film was 300Å thick was about half of a cell whose alignment film was 600Å thick. Thus, we used 300Å thick alignment film. The alignment films are formed on both of a substrate on which TFTs are formed and a substrate on which a color filter is formed. The direction of the normal lines of the layers in the cell, which is subjected to one-side rubbing, differs slightly from the rubbing direction. Therefore, the normal lines of the LC layer in the cell, whose both sides are rubbed in the same direction, are different from each other. As a result, the orientation is disordered, and the contrast is degraded. To obtain a cell whose both sides are rubbed and which has a good orientation, the direction of the rubbing on both substrates were adjusted. The viscosity of the smectic LC material is very large, so that, the LC was injected in isotropic phase. The molecule orientation of the LC was performed at a transition point isotropic-smectic A.

Prototype Display

The TLAFLC device shows electro-optic characteristics without hysteresis. Because of this, it does not require any reset pulse. Therefore, the gray scale of the cell can be controlled with simple driving wave forms like those the TN-LCD has. Table 2 shows the specification of the TLAF-TFT-LCD. Fig. 5 shows the viewing angle dependence of the TLAF-TFT LCD.

Table 2 Display specification of TLAF-TFT LCD

Display Area	5.5inch diagonal
Electrodo configuration	240×(320×3)
Scanning time per line	60 μs
Refresh frequency	30Hz
Driving Voltage	±2.5V
Contrast ratio	>100

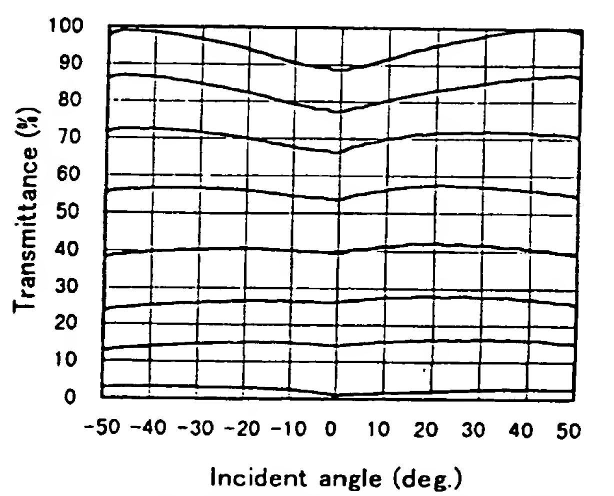


Fig. 5 Viewing angle dependence of TLAFLC

(a)

(b)

(c)

Fig. 6 Displayed images on TLAF-TFT LCD
This figure is reproduced in color on page 1134.

Although the contrast of the TLAF-TFT LCD in the normal direction was almost the same as that of the TN-TFT, the colors of displayed image on the TLAF-TFT LCD was not shifted over a satisfied wide viewing angle. Refresh frequency is 30Hz, at which flicker was not observed. No image sticking was observed even if very slow moving images were displayed. Because, there is no accumulation of the charges caused by impurity ions and the spontaneous polarizations of the LC at the interface between the LC layer and the alignment film. We were able to observe that this prototype display could display moving TV images, and a displayed image hardly had a color shift caused by changing of the viewing angle. Fig. 6 (b) shows displayed image at normal angle, and Figs. 6 (a) and (c) show displayed images at difference angles. It can be seen that the display images at different directions have no gray scale inversion and color shift.

Conclusion

This paper introduced a new technology which combines the TLAFLC with the TFT technique. And we proved that this technology brings us the extremely wide viewing angle and good gray scale characteristics, which are not obtained by other LCD techniques. by confirming the displayed images on the accomplished 5.5 inch diagonal 240×320×3 dots prototype display. Subjects must be solved in the future are. establishing mass production process techniques. enlarging the range of operation temperature. developing uses. and the like.

Acknowledgment

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